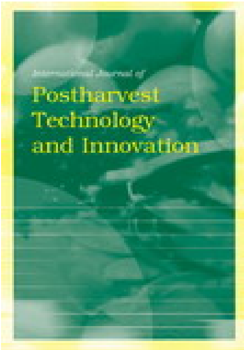

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Quality profile of different vegetables dried using simple solar dryers

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Abstract: Simple solar dryers with rotary chimney (SDR) and of tunnel type (SDT) with transparent polyethylene cover and black polyethylene cover (SDT-B) were tested in dehydrating tomato, onion, cabbage and spinach. Solar dryer temperatures increased by 5–15°C relative to that in open sun-drying. Tomatoes, onions, cabbage and spinach dried in 47, 44, 27 and 24 hours in SDR, respectively, and 51, 48, 31 and 28 hours in SDT, respectively, or 20–44 hours earlier than sun-drying. SDT-B took a longer time to dry cabbage and spinach than other solar dryers. Solar-dried onion and cabbage had high rehydration ratio. Colour (L*, a* and b*) of dried products was not affected except for SDT-B that maintained the green colour of spinach. However, vitamin C content as nutritional indicator decreased in the dried products. Future studies could look into techniques to minimise nutritional loss during solar drying of vegetables.

Keywords: vegetable dehydration; solar drying; shelf life extension.

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1 Introduction

Vegetables are high-value nutritious crops. They are rich sources of vitamins, minerals, fibres and other bioactive compounds (e.g., antioxidants, micronutrients) which could lower the risks of cancer, heart attack, diabetes and other chronic diseases if regularly consumed at a daily minimum of 3 servings or 240 g per person (Slavin and Lloyd, 2012; Kalmpourtzidou et al., 2020). However, vegetables are highly perishable due to their high water content, which contributes to high postharvest losses of up to 50% (Kordylas, 1990; Acedo and Easdown, 2015). Even under the most controlled storage conditions, fresh vegetables cannot be kept long because they continue to lose water and are subject to physiological and microbiological spoilage.

Drying or dehydration could mitigate the perishability problem of vegetables and reduce postharvest losses (Pal et al., 2016). Sun-drying in open areas is the common practice; however, it requires large spaces and long drying periods and is dependent on weather which has become more unpredictable due to climate change. Sun drying also exposes the vegetable to food safety hazards, such as dust, insects and microbes. To overcome the constraints from open sun-drying, solar dryers could be used. A solar dryer could accelerate drying due to higher temperatures than that in open sun-drying, protect the produce from rain, avoid food safety hazards, and produce better quality and safe products. It is one of the most efficient and cost-effective, renewable, and sustainable technologies for agricultural produce preservation as described in recent reviews (Patil and Gawande, 2016; Tiwari, 2016; Udomkun et al., 2020; Gorjian et al., 2021).

Simple and low-cost solar dryers are usually of the passive type with direct or indirect heat transfer, consisting of a separate solar collector (for indirect passive solar dryer) and drying chamber covered with transparent plastic sheet which can serve as a solar collector in direct passive solar dryer (Patil and Gawande, 2016). Solar dryers can be cabinet, tunnel or house type and are usually provided with air inlet for heated air transfer and circulation to facilitate extraction of moisture from the produce and air outlet to dissipate excess heat and air humidified by the extracted moisture from the produce. In South Asia where temperatures in low-lying areas may exceed 40°C during summer, proper air circulation and heat dissipation could prevent too high temperatures. In Southeast Asia, the World Vegetable Center (WVC) developed simple solar dryers (indirect passive solar dryer with rotary chimney and cabinet solar dryer covered with transparent polyethylene sheet) that can maintain temperatures of 15–35°C higher than open sun-drying conditions (Acedo et al., 2016). The solar dryers dried tomato and eggplant slices, whole chilli fruit, cabbage shreds and cauliflower florets to less than 10% moisture content in 1–3 days compared to 2–6 days under open sun-drying. However, too high temperatures (>60°C) resulted in low quality product due to discoloration and loss of critical nutrients and antioxidants.

This study determined the suitability of the WVC-developed indirect passive solar dryer with rotary chimney and a tunnel-type solar dryer with modified plastic cover for drying selected vegetables under South Asia conditions.

2 Materials and methods

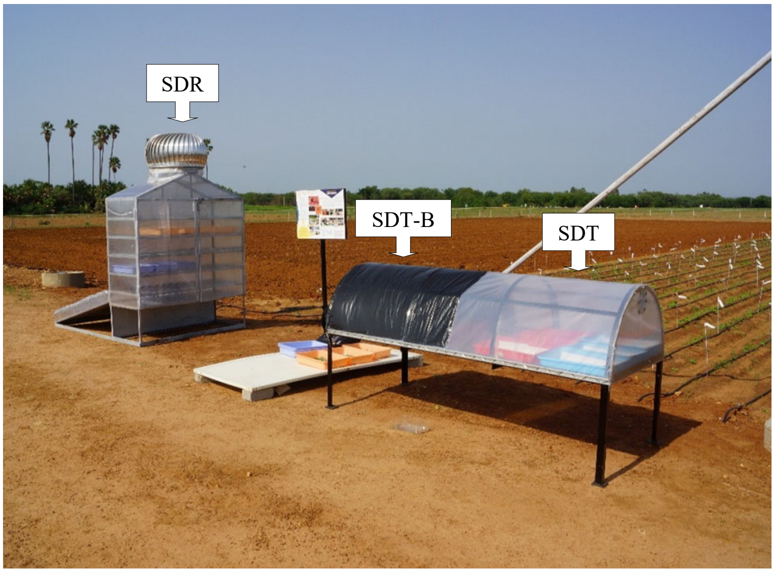
2.1 Simple solar dryers

This study was conducted at the WVC-South Asia, ICRISAT Campus, Patancheru, Telangana, India. The simple solar dryer with rotary chimney (SDR) developed under Southeast Asia context was adopted (Figure 1). SDR had a solar collector from which the heated air was conveyed to the drying chamber equipped with drying trays, transparent polycarbonate walls, and aluminium rotary chimney at the topmost part to circulate air in the drying chamber and dissipate excess heat in order to maintain temperatures below 60°C. In addition, a tunnel type solar dryer (SDT) was also tested and its plastic cover was modified. Half of SDT was covered with UV-treated 200 μm-thick transparent polyethylene film while the other half was covered with a 200 μm-thick black polyethylene film to avoid too high temperatures in the drying chamber and prevent direct light exposure as possible control of green colour loss in leafy produce. SDT consisted of a tunnel type semi-cylindrical drying chamber and was provided with air inlet to allow the ambient air to enter the dryer. An air outlet was also provided to dissipate the moist air from the dryer and maintain the desired temperature. Both the air inlet and outlet were covered with meshed net to protect the produce from insects, rodents and other contaminants. A small door was provided to facilitate easy handling of the produce. The transparent polyethylene film transmitted solar radiation into the drying chamber thereby raising its temperature. With the black polyethylene film, less solar radiation entered the drying chamber thereby modulating its temperature and preventing direct light exposure of produce. Open sun drying served as control.

2.2 Vegetable samples

Tomato var. Arka Saurabh at the firm-ripe stage and commercially mature onion var. Bhima Kiran, cabbage var. golden acre and spinach var. Pusa Harit were procured from the local market. Good quality vegetable samples were selected based on uniformity in size and shape and freedom from defects. The selected samples were thoroughly washed in clean water to remove dirt and other foreign debris. The tomatoes, onions and cabbage were sliced with a sharp stainless-steel knife into sizes of about 2–5 mm while for spinach, whole leaves were used. Triplicates of tomato (500 g/replicate), onion (550 g/replicate), cabbage (450 g/replicate) and spinach (250 g/replicate) were spread uniformly on drying trays in a single layer and placed in the SDR, SDT or under open sun drying condition. Tomato and onion dried in SDT were situated under the transparent polyethylene film cover. For cabbage and spinach dried in SDT, two sets of samples were prepared; one set placed under the transparent polyethylene cover (SDT) while the other set under the black polyethylene cover (SDT-B) (Figure 1). Considering the capacity of the drying trays, the weight mass of the spinach and cabbage used for dehydration was less than that of tomato and onion.

Figure 1 Simple solar dryers used in this study – solar dryer with rotary chimney (SDR) and tunnel type solar dryer (SDT) covered with transparent and black polyethylene film (see online version for colours)



2.3 Parameters measured

2.3.1 Temperature and relative humidity

The temperature and relative humidity (RH) in the solar dryers and under open sun drying condition were monitored three times a day (8:00 am, 1:00 pm and 5:00 pm) using an infrared thermometer (Testo 835-H1, USA) and hygrometer (MRC MT701, India), respectively.

2.3.2 Moisture and dry matter content

About 10 g of samples of each vegetable was taken and kept in an electric oven at 105 ±1°C until constant weight. The initial mass (Mt) and final mass (Md) of the samples were recorded using an electronic weighing balance (CL 501, TR Turoni, Italy). The percent moisture content on a wet basis (Mwb) was calculated using the following formula [equation (1)]:

$$\text{Mwb} = \frac{\text{Mt} - \text{Md}}{\text{Mt}} \times 100 \quad (1)$$

The number of hours for the vegetable samples to reach less than 10% moisture content was recorded. On the other hand, dry matter content was calculated as 100% – Mwb.

2.3.3 Rehydration ratio

Rehydration ratio is one of the important factors in the dehydrated products. The original weight percentage gained by a dried sample in water at a given temperature in a given time is known as the rehydration ratio and mainly depends on the porosity of the product (Conrad, 2005). Rehydration ratio was determined following the standard AOAC (2004) method and was calculated using the following formula [equation (2)]:

$$\text{Rehydration ratio} = \frac{\text{Weight of rehydrated sample}}{\text{Weight of dehydrated sample}} \times 100 \quad (2)$$

2.3.4 Colour

Colour coordinates L*, a* and b* values were measured using a colour reader (Minolta CR-10, Japan). Colour measurements were performed on the surface of the dried produce at three points. L* shows the degree of lightness to darkness, a* degree of redness to greenness, and b* the degree of yellowness to blueness.

2.3.5 Vitamin C content

As nutritional indicator, vitamin C content was analysed following the AOAC indophenol method (AOAC, 2004) and vitamin C loss was calculated as percentage of the initial vitamin C content (fresh produce). 10 g of samples of each vegetable was ground thoroughly with 20 ml metaphosphoric acetic acid using a mortar and pestle. The mixture was filtered through a muslin cloth. The extract was added with metaphosphoric-acetic acid to make the volume to 100 ml. Sample extract (2 ml) was added to 5 ml metaphosphoric acid-acetic acid solution in a 50 ml Erlenmeyer flask. The reaction mixture was titrated with the indophenol dye solution to obtain a light rose pink that persisted for 5 seconds and the amount of dye used in the titration was used to determine vitamin C content.

2.4 Statistical analysis

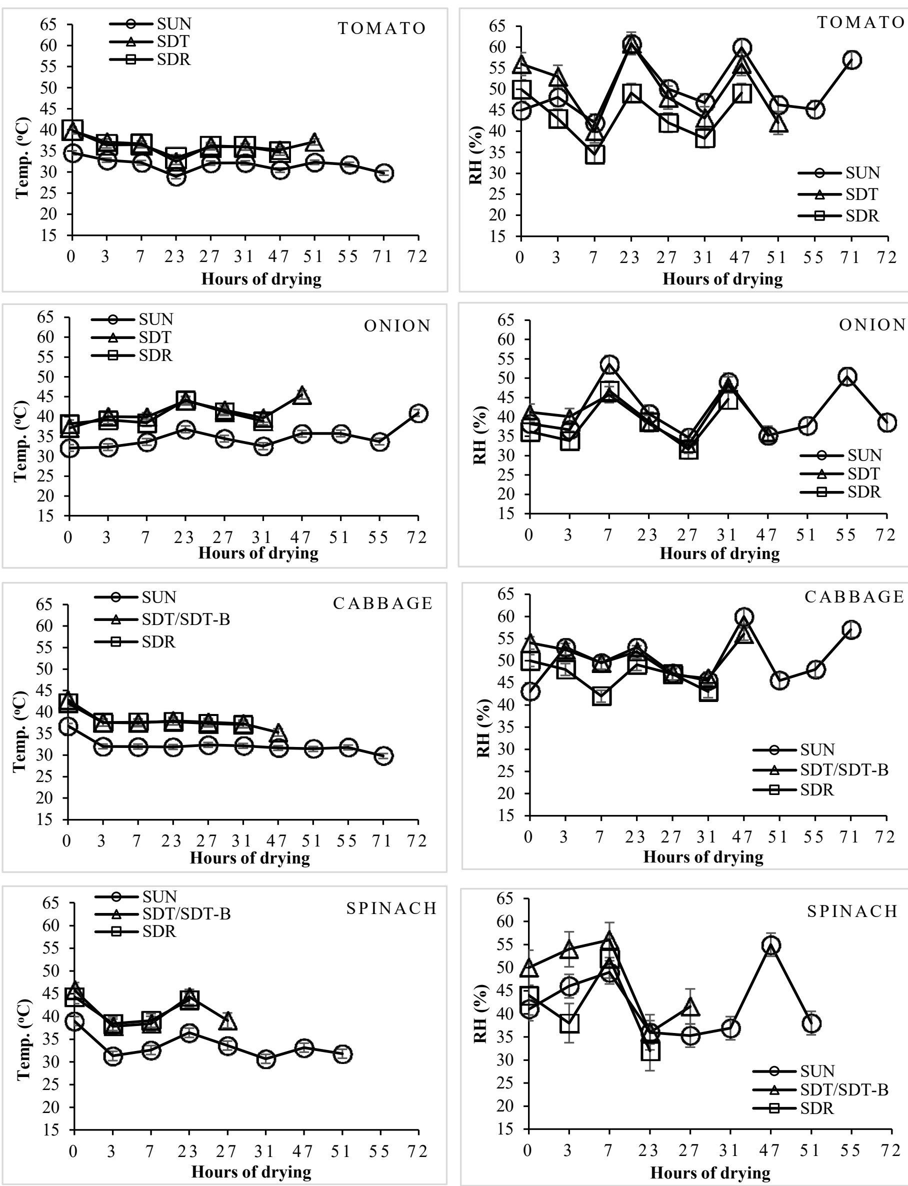
A completely randomised design (CRD) with three replications was followed. Data were analysed by analysis of variance (ANOVA) and the general linear model (GLM) using the SAS software (SAS 9.2; SAS Institute Inc., Cary, NC, USA). Treatment means were differentiated using Fisher's least significant difference (LSD) test.

3 Results and discussion

3.1 Drying temperature and RH

The two solar dryers (SDR and SDT) maintained higher temperatures and lower RH than that under open sun-drying (Figure 2). SDR had higher temperatures and lower RH than SDT. Drying temperatures for tomato ranged from 33.4–39.9°C in SDR, 32.6–39.8°C in SDT, and 29–34.6°C under sun-drying; for onion, 38.2–44.2°C in SDR, 37.2–45.5°C in SDT and 32.1–40.9°C under sun-drying; for cabbage, 37.1–42.1°C in SDR, 35.3–42.8°C in SDT, and 29.8–36.8°C under sun-drying; and for spinach, 38.4–44.3°C in SDR, 37.8–45.8°C in SDT, and 30.7–39°C under sun-drying for spinach. On the other hand, drying RH for tomato ranged from 34.5–50% in SDR, 40-60.9% in SDT, and 42–60.8% under sun drying; for onion, 31.7–46.8% in SDR, 32.7–48.3% in SDT, and 34.7–53.7% under sun-drying; for cabbage, 46–56% in SDR, 42–50% in SDT, and 43–60% under sun-drying; and for spinach, 32–52% in SDR, 36-56% in SDT, and 35.3–55% under sun-drying.

Figure 2 Temperature and RH during drying of tomato, onion, cabbage and spinach by sun drying (SUN) or using simple solar dryer with rotary chimney (SDR) or tunnel type solar dryer (SDT) covered with transparent and black polyethylene film



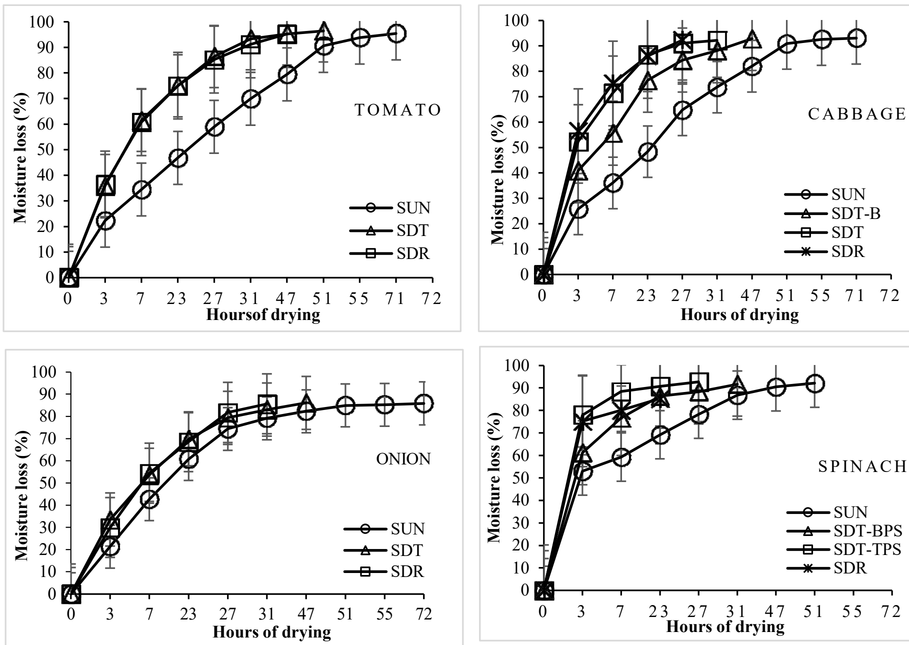
Temperature and RH are important factors on which drying of fruits and vegetables depends (Brown, 2000). Solar dryers trap radiant energy and concentrate heat inside the drying chamber, which results in higher temperatures and lower RH inside the drying chambers than ambient conditions. The heating of air inside the chamber reduces the humidity, thus, increasing its efficiency to remove moisture from the produce (Dadashzadeh, 2006). However, too high temperature (>60°C) is injurious to quality of the dried product due to colour and nutrient losses (Acedo et al., 2016). This is a problem in passive solar dryers, particularly the tunnel type (e.g., SDT) in which air circulation to dissipate excess heat cannot be controlled. The results of the present study indicate that the rotary chimney in SDR and the black plastic cover in SDT were able to maintain temperatures below injurious level. The rotary chimney in SDR draws the heated moist air from the drying chamber and expels to the outside environment as observed previously during tomato drying (Phon et al., 2017) while the black polyethylene cover in SDT blocks light thereby reducing heat inside the tunnel.

3.2 Drying rate of vegetables

Drying of the four vegetables was fastest in SDR followed by SDT and was slowest under open sun drying (Figure 3). SDT-B also dried cabbage and spinach faster than sun drying but was slower than SDT and SDR. This response was also reflected in the number of hours required to reduce the moisture content of the vegetables below 10% (Table 1). In tomato, SDR took 47 hours to reduce the moisture content from the initial level of 96% (before drying) to 6% followed by SDT (51 hours) and sun-drying (71 hours). In onion, moisture content decreased from 81% to 5.5% in 44 hours in SDR, 48 hours in SDT and 72 hours in sun drying. Cabbage was dehydrated from 93% to 5% moisture content in 27 hours in SDR, 31 hours in SDT, 47 hours in SDT-B and 71 hours in sun drying. In spinach, moisture content decreased from 95% to 5% in 24 hours in SDR, 28 hours in SDT, 44 hours in SDT-B and 52 hours in sun drying.

Drying rate followed the trend in temperature and RH. Temperature was highest and RH was lowest in SDR which consequently caused the fastest drying. Conversely, temperature was lowest and RH was highest under open sun-drying conditions, resulting in the slowest rate of drying. In cabbage and spinach, the differences in drying rate between SDT and SDT-B were anticipated as the produce placed under the transparent polyethylene cover of the tunnel received the transmitted light thereby directly heating the produce while heating of those placed under the black polyethylene cover depended entirely on the air temperature and RH inside the tunnel. Transparent plastic delivers direct light which heats the structure and the material it contains while black plastics deprives light from the structure reducing heating due to solar radiation (Brown et al., 1991). Several works have shown that solar dryers considerably reduced the drying time compared to conventional sun drying (Patel et al., 2013), specifically in chilli (Joy et al., 2001), tomato (Phon et al., 2017) and cauliflower (Gautam et al., 2017). Drying time also differed with the produce due to differences in morpho-anatomical and chemical composition, including moisture content, size, shape, and tissue or cell characteristics. This may also account for the differences in drying rate of the four vegetables in this study.

Figure 3 Moisture loss during drying of tomato, onion, cabbage and spinach by sun drying (SUN) or using simple solar dryer with rotary chimney (SDR) or tunnel type solar dryer (SDT) covered with transparent and black polyethylene film



3.3 Rehydration ratio

Rehydration ratio of dried tomatoes was highest in the sun drying treatment (4.3) followed by that in SDR (4.1) and SDT (3.9) (Table 1). SDR-dried onions attained better rehydration ratio of 10.3 followed by that in SDT (10.2) while sun dried onions had the lowest rehydration ratio of 9.2. The same trend was obtained for cabbage with the highest rehydration ratio of 9.2 in SDR followed by SDT and SDT-B (8.2) and sun-drying (8.0). In spinach, the rehydration ratio followed the same trend as tomato, with sun-drying having the highest rehydration ratio (6.8) followed by SDR (6.4), SDT-B (6.1) and SDT (5.7).

Most dried food products are rehydrated before consumption. Rehydration ratio determines the quality of the dried product. The higher the rehydration ratio, the better the quality of the dried product as the pores in the dried material allow water to re-enter the cells (Noomhorm, 2007). The higher rehydration ratio of sun-dried tomatoes and spinach in the present study may be attributed to the more uniform exposure to drying conditions and better heat transfer, resulting in reduced textural changes compared to that of the other drying treatments. Differential rehydration ratio has been reported in dried products of carrot (Strom, 2011), sweet potato (Pandey and Singh, 2011) and tomato (Sacilik et al., 2006). In amaranth, sun-dried products had higher rehydration ratio than shade-dried ones (Rajeswari et al., 2011).

Table 1 Drying period and rehydration ratio of tomato, onion, cabbage and spinach dried by sun drying (SUN) or using simple solar dryer with rotary chimney (SDR) or tunnel type solar dryer (SDT) covered with transparent and black polyethylene film

Vegetable	*Drying method*	*Hours to <10% moisture content*	*Rehydration ratio*
Tomato	SUN	71a	4.3a
	SDT	51b	3.9b
	SDR	47b	4.1ab
	CV, %	5.0	1.6
	LSD 5%	9.0	0.2
Onion	SUN	72a	9.2c
	SDT	48b	10.2b
	SDR	44b	10.3a
	CV, %	5.1	0.2
	LSD 5%	9.0	0.08
Cabbage	SUN	71a	8.0b
	SDT-B	47b	8.4b
	SDT	31c	8.2b
	SDR	27c	9.2a
	CV, %	5.0	3.0
	LSD 5%	6.2	0.7
Spinach	SUN	52a	6.8a
	SDT-B	44b	6.1b
	SDT	28c	5.7c
	SDR	24c	6.4b
	CV, %	7.6	2.0
	LSD 5%	7.8	0.3

Note: Mean separation within columns per commodity by LSD, 5%.

3.4 Quality of dried vegetables

In dried tomato, L* (lightness), a* (green/red coordinate; increasing values indicate reddening) and b* (blue/yellow coordinate; increasing values indicate yellowing) did not widely vary with drying treatment (Table 2). However, L*, a* and b* values were markedly lower in the dried product than in the fresh produce, indicating darker colour (low L*), loss of red colour (low a*) and blue colour (low b*). SDR maintained more red colour indicated by significantly higher a* values (10.2) than that of SDT (6.5) and sun-drying (10.0). In onion, L* values did not differ between the fresh and dried product while a* values were lower and b* values were higher in the dried product than in the fresh produce. Higher b* value indicates yellowish colour of the dried product. In cabbage, drying resulted in loss of lightness (low L* values) and green colour (high a* and b* values) regardless of drying treatment relative to that of fresh produce. The use of SDT-B proved to be ineffective in retaining the green colour of the dried cabbage shreds. However, in spinach, browning or colour darkening was avoided indicated by similar or higher L* values compared to that of the fresh produce. In addition, all three solar dryers were effective in retaining the green colour (low a* values) and minimising yellowing (low b* values) of the dried product.

Table 2 Quality characteristics of tomato, onion, cabbage and spinach dried by sun drying (SUN) or using simple solar dryer with rotary chimney (SDR) or tunnel type solar dryer (SDT) covered with transparent and black polyethylene film

Vegetable	*Drying method*	*Colour*			*Moisture content (%)*	*Dry matter content (%)*
		*L**	*a**	*b**		
Tomato	SUN	40.8 ± 2.61b	10.0 ± 2.25c	5.7 ± 1.93b	4.5 ± 0.03b	4.9 ± 0.10
	SDT	39.8 ± 1.47b	6.5 ± 0.85c	5.1 ± 1.26b	5.3 ± 0.69b	4.6 ± 0.06
	SDR	39.6 ± 1.12b	10.2 ± 1.96b	5.6 ± 1.64b	6.3 ± 1.36b	4.5 ± 0.08
	Fresh	53.7 ± 2.34a	20.0 ± 1.74a	50.5 ± 2.11a	93.7 ± 2.34a	6.3 ± 1.74
	CV, %	4.7	20.2	29.8	16.5	1.9
	LSD 5%	3.6	3.5	3.2	1.7	0.1
Onion	SUN	58.6 ± 2.68a	4.5 ± 0.40c	13.0 ± 0.55a	5.6 ± 0.45b	14.7 ± 0.21
	SDT	55.5 ± 2.46a	6.9 ± 0.15b	15.7 ± 2.57a	3.8 ± 0.66c	13.9 ± 0.04
	SDR	54.7 ± 1.34a	4.6 ± 1.43c	9.6 ± 0.79b	5.4 ± 1.23b	14.3 ± 0.66
	Fresh	57.4 ± 2.10a	13.3 ± 0.87a	–4.4 ± 1.21c	80.8 ± 2.12a	19.2 ± 1.12
	CV, %	4.0	16.3	12.5	17.4	2.6
	LSD 5%	4.4	1.7	3.1	1.7	0.8
Cabbage	SUN	63.4 ± 1.05b	6.0 ± 0.43b	17.2 ± 0.45ab	5.4 ± 0.54b	6.9 ± 0.18
	SDT-B	57.1 ± 1.46c	6.6 ± 0.92a	16.4 ± 0.05ab	7.1 ± 1.09b	7.9 ± 0.20
	SDT	60.3 ± 4.14bc	7.3 ± 0.70a	17.7 ± 1.66a	6.0 ± 1.72b	6.5 ± 0.18
	SDR	62.1 ± 1.23b	6.2 ± 0.53ab	15.8 ± 0.94b	4.9 ± 1.22b	7.0 ± 0.18
	Fresh	86.2 ± 2.12a	–0.2 ± 0.06c	13.5 ± 1.23c	92.7 ± 2.35a	7.3 ± 0.72
	CV, %	3.9	10.4	5.9	20.8	2.7
	LSD 5%	4.4	1.2	1.8	2.3	0.3
Spinach	SUN	45.1 ± 1.41b	1.2 ± 0.03a	7.5 ± 0.92a	4.3 ± 0.17b	7.9 ± 0.31
	SDT-B	43.8 ± 2.35b	–2.0 ± 0.50b	6.1 ± 2.05b	5.1 ± 1.20b	8.3 ± 0.30
	SDT	52.0 ± 1.38a	–1.6 ± 0.30b	9.7 ± 1.8b	5.9 ± 1.35b	7.3 ± 0.06
	SDR	46.9 ± 3.66b	–3.3 ± 0.88c	6.7 ± 2.03b	5.7 ± 1.08b	8.7 ± 1.72
	Fresh	43.1 ± 1.82b	–9.7 ± 1.23c	23.9 ± 1.24a	94.8 ± 2.61a	5.2 ± 2.12
	CV, %	5.1	–22.4	22.6	20.1	11.1
	LSD 5%	4.5	1.0	2.9	1.9	1.6

Note: Mean separation within columns per commodity by LSD, 5%.

The colour of the dried product is an important quality factor that determines market acceptability. Colour changes in a product during drying depend mainly on colour pigments, browning by enzymatic reactions and Maillard reactions (Marty-Audouin et al., 1999). The use of black polyethylene cover (SDT-B) was thought to improve green colour retention particularly in leafy vegetable samples owing to the fact that direct exposure to light may induce photo-oxidation and loss of the chlorophyll pigment (Brenndorfer et al., 1985; Gomez, 1981). The results of the present study suggest the absence of this factor influencing changes in green pigmentation. The variation in colour of dried vegetables is related to the combined effect of drying temperature and time duration of drying. Brenndorfer et al. (1985) reported that introduction of a black cover (under clear cover) in a solar dryer reduced loss of colour, vitamin and nutrients as a result of direct exposure to sunlight in green leafy vegetables. Pandhre et al. (2011) reported that when fenugreek leaves were dried using solar, infra-red and tray dryer there was a loss of colour pigments. Gomez (1981) reported significant improvement in carotene retention of green leafy vegetables dried in the solar dryer covered with black sheet compared to those dried by exposure to sun.

Moisture content of the dried product was not significantly different across the drying methods (Table 2). It decreased from 80.8–94.8% in fresh produce to 4.5–6.3% in dried tomato, 3.8–5.6% in dried onion, 5.4–7.1% in dried cabbage and 4.3–5.9% in dried spinach. These results conform to earlier reports of Bala et al. (2009) and Eze and Agbo (2011). On the other hand, dry matter content did not show significant differences between fresh and dried products and ranged from 4.5–6.3% in tomato, 13.9–19.2% in onion, 6.5–7.9% in cabbage, and 5.2–8.7% in spinach. Earlier studies showed significant differences in dry matter content of fresh and dried products (Suna et al., 2014; Mohammed et al., 2020). The results of the present study suggest that the drying treatments did not cause significant respiratory losses of food reserves in the produce probably because of the short time period to drying (at most 72 hours).

3.5 Vitamin C content

Vitamin C content decreased in response to drying (Table 3). In tomato, it decreased from 16.8 mg/100 g fresh weight (FW) in fresh produce to 11.4–13.0 mg/100 gFW in the dried product, representing a loss of 22.4–32.2%; in onion, from 6.8 mg/100 gFW for fresh produce to 5.1–6.1 mg/100 gFW for the dried product or a loss of 10.3–24.2%; in cabbage, from 35.2 mg/100 gFW to 16.7–19.0 mg/100 gFW or a loss of 45.9–52.5%; and in spinach, from 27.5 mg/100 gFW to 5.2–9.3 mg/100 gFW or a loss of 66–81%. The use of solar dryers had no distinct advantage over sun-drying in minimising vitamin C loss.

Vitamin C (ascorbic acid) is water soluble and sensitive to heat, light, and oxygen (Rajkumar, 2007; Acedo and Easdown, 2015). It is used as an important marker of nutritional quality as it is highly unstable and is lost during drying (Cernişev and Sleagun, 2007). Our results are in agreement with previous findings. Hussein et al. (2016) reported that 40% vitamin C was lost in tomatoes dried in solar dryer while Toor and Savage (2006) reported 17–27% vitamin C loss during drying depending on tomato variety. Higher drying temperatures and longer drying time could result in more vitamin C loss. For example, drying of tomatoes at 80°C or higher resulted in vitamin C losses of more than 80% (Lavelli et al., 1999; Goula and Adamopoulos, 2006). Vitamin C loss occurred regardless of the type of dryer, may it be cabinet or tunnel type (Mongi, 2013). In amaranth, about 83% of vitamin C was lost in the sun-dried product (Ogbadoyi et al., 2011). Vitamin C in dried products has been linked to the thickness of polyethylene cover of dryers, dryer temperature, drying period, and air circulation in the drying chamber (Giovanelli et al., 2002). Furthermore, vitamin C loss forms part of unseen postharvest losses which should be reduced to maximise the nutritional value of vegetables. Some losses are inevitable but in some dried products, high concentrations of ascorbic acid can be retained depending on the method and rate of drying (Bonazzi and Dumoulin, 2014).

Table 3 Vitamin C content and losses in tomato, onion, cabbage and spinach dried by sun drying (SUN) or using simple solar dryer with rotary chimney (SDR) or tunnel type solar dryer (SDT) covered with transparent and black polyethylene film

Vegetable	*Drying method*	*Vitamin C (mg/100 g)*	*% loss of vitamin C*
Tomato	SUN	13.0 ± 1.27b	22.4 ± 5.23
	SDT	12.7 ± 0.70b	24.4 ± 1.66
	SDR	11.4 ± 1.41b	32.2 ± 6.13
	Fresh	16.8 ± 1.63a	
	CV,%	9.4	26.4
	LSD 5%	3.7	NS
Onion	SUN	6.1 ± 0.42a	10.3 ± 4.37b
	SDT	5.2 ± 0.07b	22.7 ± 2.64ab
	SDR	5.1 ± 0.21b	24.2 ± 4.69a
	Fresh	6.8 ± 0.89a	
	CV,%	5.0	20.9
	LSD 5%	0.8	12.7
Cabbage	SUN	19.0 ± 0.63b	45.9 ± 0.58b
	SDT-B	17.8 ± 2.26b	49.5 ± 4.19ab
	SDT	17.8 ± 0.63b	49.3 ± 0.43ab
	SDR	16.7 ± 0.84b	52.5 ± 0.32a
	Fresh	35.2 ± 0.89a	
	CV,%	7.2	4.3
	LSD 5%	3.6	5.9
Spinach	SUN	9.3 ± 0.76b	66.1 ± 2.24
	SDT-B	6.1 ± 0.53b	77.8 ± 4.02
	SDT	6.4 ± 0.74b	76.7 ± 2.01
	SDR	5.2 ± 0.87b	81.0 ± 2.32
	Fresh	27.5 ± 0.78a	
	CV,%	10.7	3.5
	LSD 5%	6.2	NS

Note: Mean separation within columns per commodity by LSD, 5%.

4 Conclusions

Tomato, onion, cabbage and spinach dried faster in the SDR due to higher temperatures and lower RH than in SDT. Drying was slowest under open sun drying conditions. No remarkable differences in quality were obtained on products dried in solar dryers and sun-drying. SDT-B was effective in maintaining the green colour of dried spinach. However, all drying treatments decreased the vitamin C content of the dried product.

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